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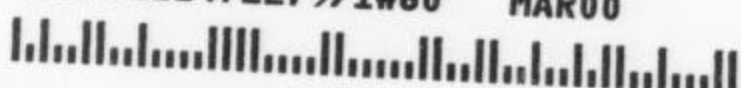
THE WORLD OF SCIENCE

APRIL 1998

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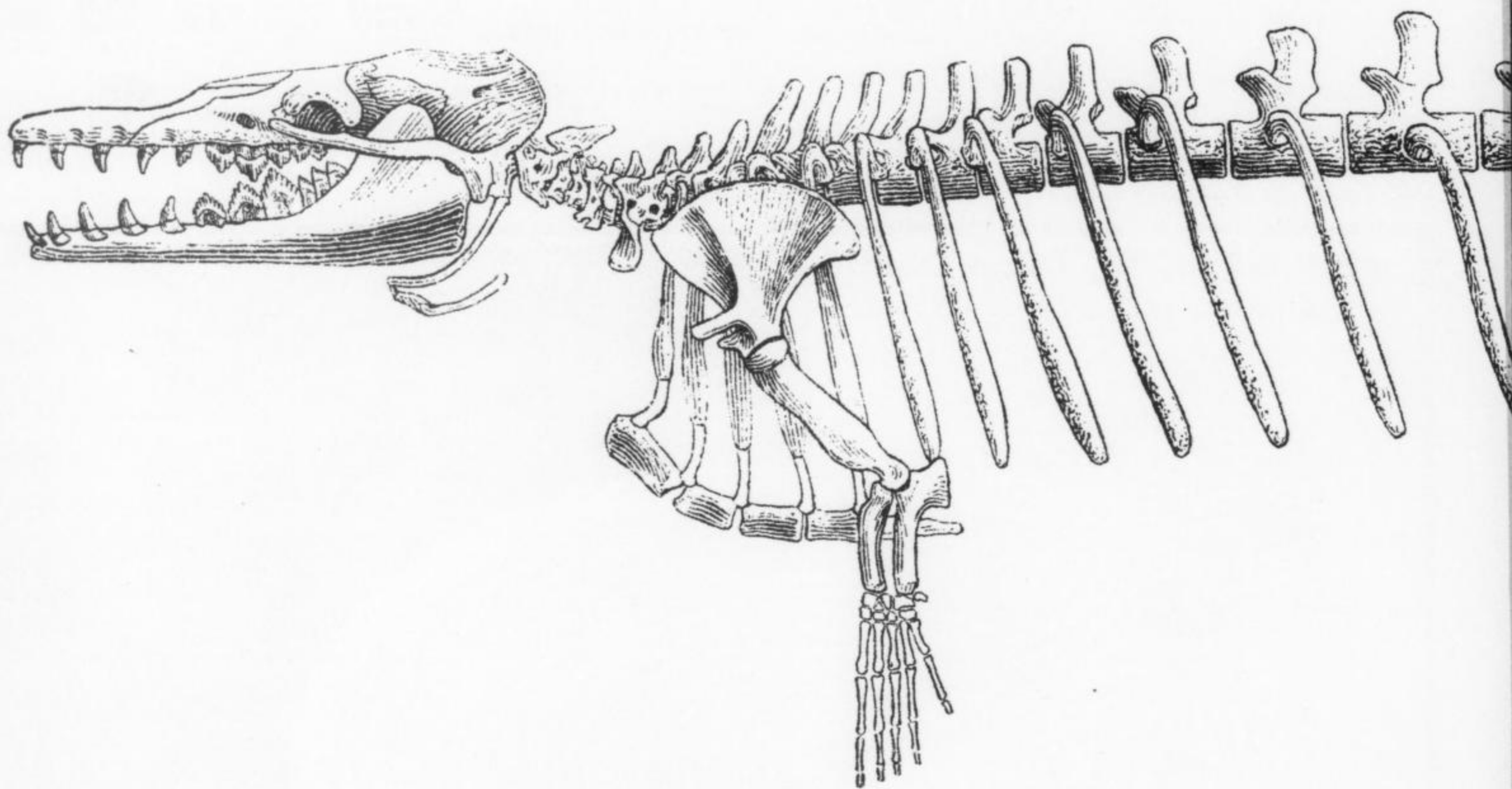
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The Equation of a Whale

BY CARL ZIMMER



In 1832 the fossilized bones of a primitive whale emerged from the earth. But appearing as they did in a pre-Darwinian age, they became the objects of furious academic controversy—and of vaudeville hucksterism.

THE EVOLUTION OF OCEAN-DWELLING WHALES from terrestrial mammals was one of the most dramatic transitions in the history of vertebrates. To go from the land back into the water left behind so many millions of years earlier called for a monstrously great change, a drastic reworking of physical form and function. It took some 10 million years to accomplish—roughly, the period from 50 million to 40 million years ago. Yet it's only in the last few years that we've come to grasp the essential facts of the story. Fossils of primitive whales had been known since the early nineteenth century, but the pioneering paleontologists of the time, not surprisingly, simply could not make sense of them—it would be decades before Darwin provided the evolutionary model that made the origin of whales understandable.

The earlier leading version of evolution was that of Jean-Baptiste Lamarck, who, though he held that species did indeed change over time, thought they did so by passing on to their offspring traits they acquired during their lifetime. In this way, he maintained, all lineages exhibited an inner striving for perfection, and creatures of ever greater com-

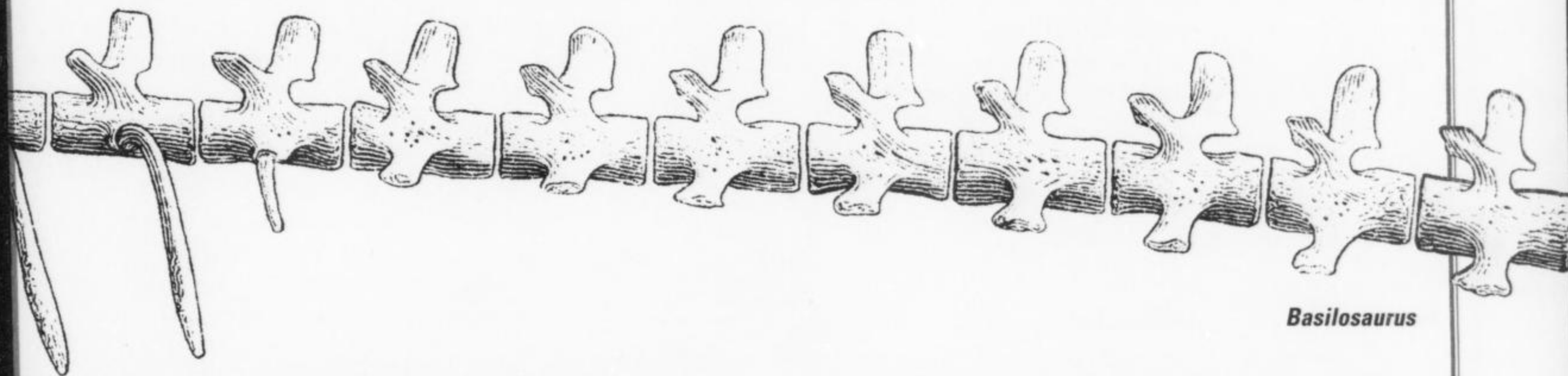
plexity and sophistication appeared upon Earth. How could such a philosophy accommodate a mammal choosing to go backward, to become an awkward caricature of a reptile? Lamarckism, meanwhile, was vigorously opposed by the great zoologist Georges Cuvier, who was using fossils to show that life had undergone many catastrophes and extinctions through time. Yet Cuvier found the anatomy of animals so distinct and so well suited to their particular functions that evolution seemed an impossibility to him. Life did not flow smoothly from one age to the next, and animals did not change from one form to another. Life shuddered over and over again with violent revolutions. In each age, animals designed exquisitely for their new landscape were created anew.

One of the things that impressed Balzac most about Cuvier was how he "rebuilt, like Cadmus, cities from a tooth." Cuvier earned that reputation in 1804 when he received the skeleton of a creature the size of a cat from the limestone

quarries of Montmartre. It had left its mark on two slabs that fit together like a muffin and its tin. The hips and legs and bits of spine were lodged in one piece of the limestone, while the rest of the skeleton lay in the other: a shoulder, an arm, and part of its jaw, its teeth half-grinning out of the rock. With no clear idea of what kind of animal this was, Cuvier brought the fossil into his museum laboratory and began looking down into the animal's mouth, chipping the bones free and sketching the details as he went.

He could see the bump on the rear of the jaw where it

hinged with the skull, a feature, called the condyle, that only mammals have. In many mammals the condyle rides high on the back of the jaw, but the creature in Cuvier's limestone had a low condyle that bulged from the jaw barely above its rows of teeth. Cuvier could thus eliminate mammals like cats, dogs, and martens all at once, because only animals such as moles, hedgehogs, bats, and opossums have such a jaw. He prized the lower jaw free and exposed both sets of teeth. They were neither sharp-edged like a carnivore's nor flattened like those of a grass-chewing cow. Instead they bristled with small pointed cusps—again, the sort shared only by mammals that have a low condyle. Under a magnifying



Basilosaurus

glass, he could see that some of the teeth were triangular, with three hooklike cusps. A mole has seven of these cusps; so does a bat; a hedgehog has four. The only mammals that have three are certain marsupials: the opossums of North and South America and their relatives and the dasyurids of Australasia (a group that includes the Tasmanian devil).

"I stopped my work on the teeth before I occupied myself with the rest of the skeleton," Cuvier wrote later, "but I could have predicted everything else from this sole index. Number of parts, forms, proportions—all this the surface of the rock offered us, was found entirely answered in that first sight."

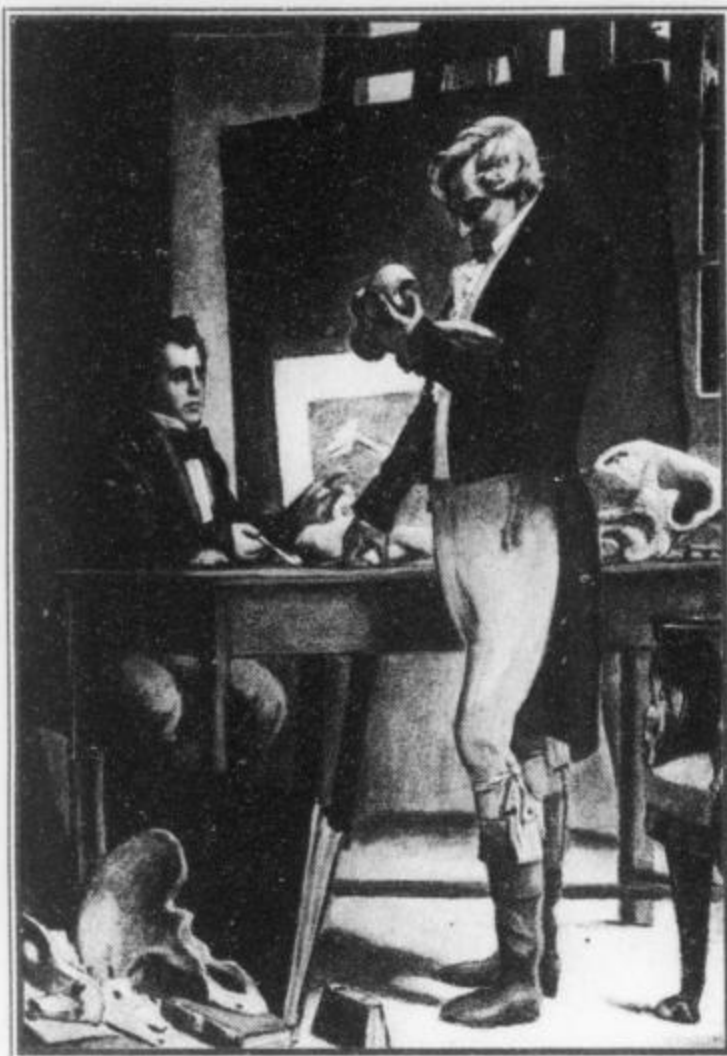
A French opossum would have been a scientific outrage. The opossum is a marsupial, and as such it gives birth to young the size of a rice grain that creep into their mother's pouch and clamp onto a nipple for months. But all living mammals in Europe are placental—they gestate in the womb, nourished by a placenta, and emerge much larger than marsupial babies. There are no living marsupials in Europe, and opossums and dasyurids live only in the New World and Australasia. Cuvier had just begun to introduce Europe to the concept of extinction, and people could still

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be skeptical. But if he was right about these new slabs, the skeptics would have a much harder time.

Cuvier had no doubt in his prediction, though, because he was convinced that the animal's anatomy was not a patchwork. Each organism is born dedicated to its own manner of life, he argued, and all of the parts of its body point toward that end. A mole's backhoe hands and its thick-walled head are not some coincidental arrangement—they are both necessary for digging tunnels underground. And because animals are so unified, their teeth can serve as miniature portraits. "Every organized creature forms a whole, a unique and closed system, whose parts mutually correspond to one another," Cuvier wrote. "In a word, the form of the tooth leads to the form of the condyle, that of the scapula to that of the nails, just as an equation of a curve implies all of its properties."

Of course Cuvier didn't know the equation of an opossum, but he could come close by studying how the parts of a body correlated with one another. With enough observation, naturalists might approach the rational laws of physics and mathematics. Cuvier badly wanted to put anatomy on a level with those sciences, to make it more than a genteel hobby of col-



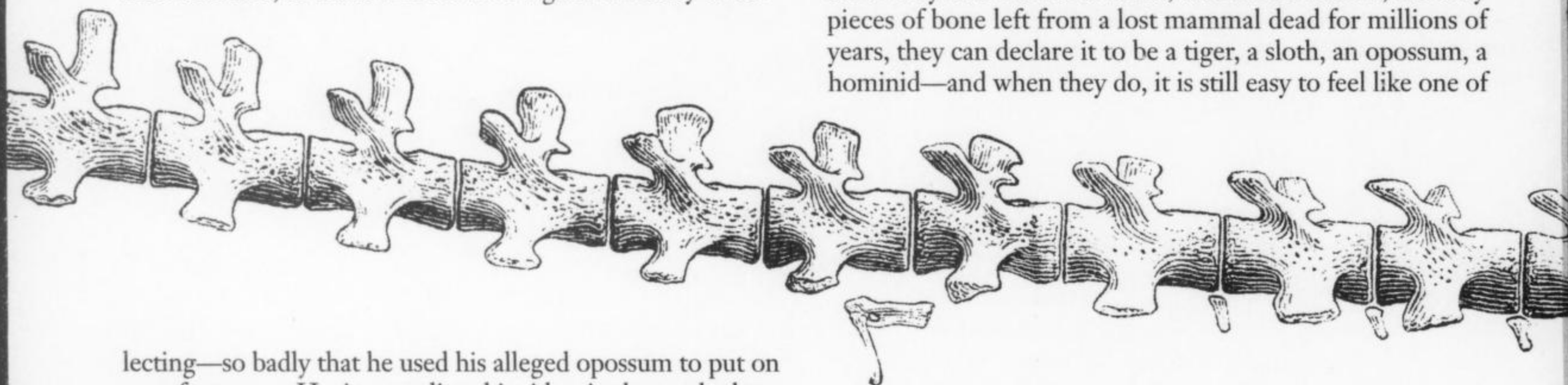
Georges Cuvier

bones surfaced side by side from the stone in front of the pelvis.

"There is no science that cannot become almost geometrical," Cuvier declared over his pouch bones. "The chemists have proved as much in recent times for theirs, and I hope that the time is not far off when one will be able to say as much of the anatomists."

Almost two centuries later, paleontologists today aren't quite so cocky as Cuvier. An animal's body isn't generated by some formula of its function. It's a product of its evolutionary history, and while factors such as the constraints of how embryos develop may give it a certain coherence, there are some fossil animals that are unlike anything alive today and others that seem as if they were stitched together from random parts. But even today teeth remain impressive taxonomic

fingerprints, at least for mammals. When we are born we are not yet skeletally set: soft bones have to cure and fuse, to grow stout as we mature, with the exception of teeth. As soon as the cusps and fissures and roots of teeth form in a baby's jaws, they keep their topography for life. If paleontologists find an isolated femur or rib, they often can't say much about its owner, but if they find a bit of cracked, weathered enamel, the only pieces of bone left from a lost mammal dead for millions of years, they can declare it to be a tiger, a sloth, an opossum, a hominid—and when they do, it is still easy to feel like one of



lecting—so badly that he used his alleged opossum to put on a performance. Having predicted its identity by teeth alone and with the rest of the fossil untouched, he brought witnesses into his chambers before finishing the job. "This operation was done in the presence of people to whom I had announced in advance the result," he wrote, "with the intention of proving to them the justice of our zoological theories, since the true seal of a theory is beyond dispute the ability it has to predict phenomena."

Chiseling the limestone, Cuvier made his way down the animal's body. He found 13 ribs, and then arm bones that were jointed to allow a creature to climb trees, six lumbar vertebrae in its back—all perfectly consistent with the animal being a relative of opossums. But to satisfy the deepest skeptic, Cuvier set these bones aside. Marsupials, as everyone knew, had pouches, and all of them were supported by two bones that protrude from the front of the animal's pelvis. The pelvis of Cuvier's fossil was facing downward, so he began to dig into the slab with a sharp steel point, his witnesses doubtless shocked as he destroyed part of the spine of this priceless fossil to get to the animal's front side. He kept digging, tearing out the sacrum and the tail, until at last two hatchet-shaped

the gentlemen at the museum in Paris, looking over Cuvier's shoulder at the still-sealed slab of limestone and thinking that a magician is at work.

FROM THE BEGINNING, THE TEETH OF WHALES HAVE helped guide paleontologists to their true history. In 1832, the year that Cuvier died, the president of the American Philosophical Society in Philadelphia received a letter and a box. The letter was from a Louisiana man who called himself Judge Bry, and inside the box was a 45-pound piece of rock the shape and size of a small powder keg. "A scientific memoir cannot be expected from one who has now spent the last 30 years of his existence literally in the remotest forests of Louisiana, whose life has during this long period been entirely devoted to agricultural pursuits," Bry wrote. Instead he simply described a hill along the Ouachita River in Caldwell Parish where he had found fossils of seashells. "About three years ago, after the occasion of a long spell of rainy weather, a part of the hill slid down near

the water's edge and thereby exposed 28 of these bones, which had been until then covered by an incumbent mass of earth about 40 feet thick. When these bones were first seen, they extended in a line, which from what the person living near this place showed me, comprised a curve measuring upwards of 400 feet in length, with intervals which were vacant. The person referred to destroyed many of the bones by employing them instead as andirons in his fireplace, and I saved what remained from the same fate. If I might presume to express an opinion as to the animal to which these bones belong, I should venture to say that they were part of a sea monster."

The fossil was put in the hands of a Dr. Richard Harlan—a surgeon, working at the Philadelphia Alms House Hospital, but one gifted in physiology, geology, zoology, and comparative anatomy as well, and one of the few paleontologists in the United States at the time. Harlan did what science he could as it came to him. When the remains of animals were brought to the American Philosophical Society, Harlan described them, whether they were condors or orangutans or mammoth teeth. He inspected a skeleton that had been found at the mouth of the Mississippi and identified as a giant oceangoing lizard, and he realized that it was actually a sperm whale.

Harlan was a careful Cuvierian. Catastrophes, he knew, had obliterated old residents of the planet and new ones had taken their place, but "between species and species, nature has drawn

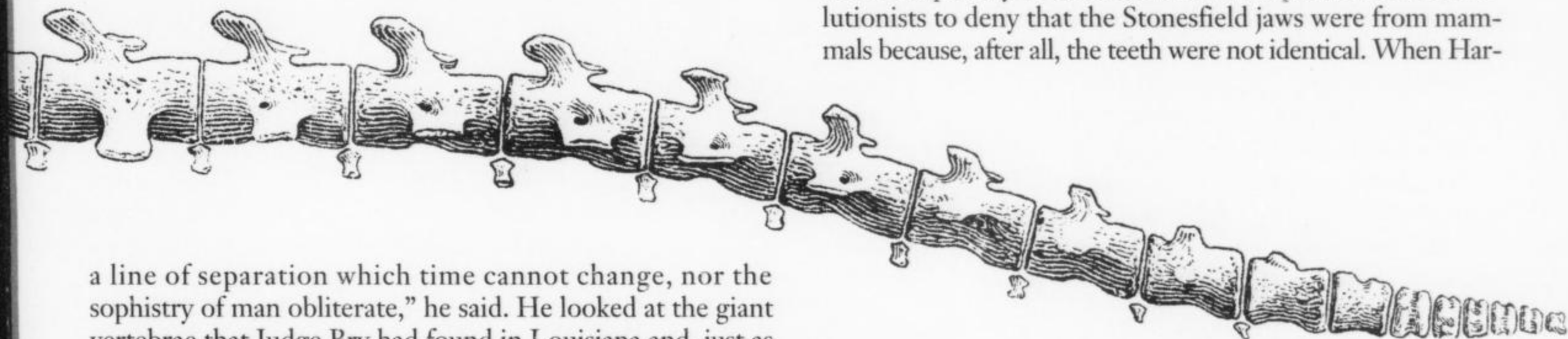


Richard Owen

a giant arm, and jaws with a few teeth still in place. The teeth, each the size of a potato, gave Harlan a little pause. Some of them were narrow, others farther back were blocky. Harlan knew that the teeth of marine reptiles, like those of all reptiles, were uniform, and that only mammals carried different kinds—molar, premolar, incisor. But although *Basilosaurus* had a varied set of teeth, its jaw was long and hollow like the jaws of marine reptiles, so Harlan stood by his previous claims. The only change he made to them was to guess now that his reptile was actually 150 feet long.

When word of *Basilosaurus* got to Europe, it was sucked into a controversy over another set of mammal teeth. Cuvier's opossum in 1804 had come from the earliest part of what is now called the Cenozoic Era, which stretches from 65

million years ago to the present. As far as anyone could tell, mammals were limited to the Cenozoic; in the preceding Mesozoic, the only vertebrates were reptiles and fishes. When Lamarckian evolutionists looked at this pattern, they found comfort: it suggested that mammals were the latest transmutation that vertebrates had gone through, and there was thus a straight line from reptile to mammal, of increasing complexity. But in 1812 the jaws of a primitive mammal turned up in a piece of slate from Stonesfield, England, dating from the Mesozoic. The notion that this mammal lived side by side with dinosaurs, unrelated and separately created, was exactly what an evolutionist of the time did not want to hear. The rocks were indisputably Mesozoic, and it was impossible for the evolutionists to deny that the Stonesfield jaws were from mammals because, after all, the teeth were not identical. When Har-



a line of separation which time cannot change, nor the sophistry of man obliterate," he said. He looked at the giant vertebrae that Judge Bry had found in Louisiana and, just as Cuvier would have done, tried to reconstruct the whole animal from them. Harlan decided that the vertebrae came from the backbone of some kind of giant extinct marine reptile, measuring perhaps a hundred feet long. "If future discoveries of the extremities and of the jaws and teeth of this reptile should confirm the indication I have pointed out," he wrote, "we may suppose that the genus to which it belonged will take the name, by acclaim, of *Basilosaurus*"—in other words, the King of Reptiles.

Just after Harlan got Bry's fossil into print in 1835, more bones came out of the south. In Alabama another judge—this one named John Creagh—found enormous bones embedded in limestone on his plantation, rock so hard he had to blast the fossils free. When Harlan was able to look at Creagh's bones, he realized some of them matched Bry's fossils, and in the same exploded rocks Creagh also managed to find ribs, bones from

lan offered the world the reptile *Basilosaurus*, with its varied set of teeth rooted in the same jaw, the evolutionists suddenly had an out: the animals of Stonesfield must be relatives of *Basilosaurus* and therefore reptiles as well. The Mesozoic Period was made mammal-free once again.

IN 1839 HARLAN WAS INVITED TO LONDON TO ADDRESS a meeting of the Geological Society. He probably had no idea of the battle into which he was being marshaled, or why the great English anatomist Richard Owen was so happy to meet him when he arrived. At the time, Owen was the English champion of Cuvier's cause, and the evolutionists' most vigorous opponent. When he looked at the Stonesfield jaws, he saw mammals, and he was determined to destroy the links that had been used to tie them to reptiles.

When Harlan arrived in London, Owen relieved him of the *Basilosaurus* teeth.

A few weeks later at the meeting, Owen took the podium. The features that Harlan thought pointed to a marine reptile Owen brushed away. A long hollow jaw could just as easily be found on a sperm whale. The vertebrae had gentle concave ends like those of mammals, not of reptiles, and the wide hole at their centers—threaded in life by a spinal cord—was the same shape as a whale's. But most important to Owen were the teeth. He had studied them closely, even slicing them open into a series of sections and looking at them under a microscope. While some of the front teeth were simple fangs, each of the rear teeth was a pair of teeth fused together midway and then fitted into a pair of sockets. No fish or reptile known had anything like it; real marine reptiles had teeth with single roots that fused to the jaw itself. Moreover, under a microscope a marine reptile tooth has a simple burst of thin tubes that

penetrates regularly spaced concentric rings. But *Basilosaurus* had the same pattern seen in marine mammals, with a thin layer of cement at the surface and undulating fine tubes just underneath. From his study of the teeth and other bones, Owen was willing to grant that this was a strange beast, but rather than a sea monster, it was a serpent-shaped whale—"one of the most extraordinary of the Mammalia which the revolutions of the globe have blotted out of the number of existing beings."

Harlan went along meekly with Owen's new take on *Basilosaurus*. He returned home to Philadelphia, where in 1842 he learned that Judge Creagh's plantation had regurgitated a 65-foot-long spine with a fair chunk of a head attached, which looked distinctly more like a whale than a reptile. He died the next year, only 47 years old, barely known at the time outside the United States and now hardly known within them.

AT ABOUT THE TIME HARLAN WAS CROWNING *Basilosaurus* in Philadelphia in 1832, a little museum opened in St. Louis. For a quarter, people could enter and watch magicians and bird imitators; they could look at Egyptian mummies in their sarcophagi, Indian mummies from Kentucky caves, wax figures of Jim Crow and Zip Coon, the famous Siamese twins, live bears and alligators, as well as paintings of the French Revolution, the tunnel under the Thames, and the Battle of Austerlitz.

The owner of the museum was a German immigrant named Albert Koch. Like Owen and Harlan, he was a paleontologist, but one without schooling or a hospital salary. When he was not running his museum, he was wandering the Mississippi Valley alone looking for fossils, fording rivers, fighting diseases, and eating nothing more than salt pork and bread. In 1839 he dug up the bones of a giant mastodon he named *Missourium* and made the skeleton pay for its discovery by

taking it on a tour of America. In Philadelphia, scientists inspecting the skeleton pointed out that he had overblown his beast, adding ten extra vertebrae from a second *Missourium* to its spine and inserting wooden blocks to make it even longer. Rather than let his giant shrink, Koch headed on to Europe

to show the fossil off at Piccadilly in 1842, proclaiming it "the sovereign masterpiece and proudest monument of all animated nature." After Owen paid it a visit, the British Museum bought it from Koch for £1,300 and squeezed it down to proper size.

Koch knew exactly what to do with the money. He immediately sailed back to the United States, lured by stories of the sea monsters of Alabama. By January 1845 he was in Clarksville, not far from where Judge Creagh had blasted his bones free, and discovered that *Basilosaurus* vertebrae were so common they had become furniture in the region, propping up logs in a fireplace or wedged between beehives. But a full skeleton eluded Koch for months, as he un-

covered only shark teeth and other bits of marine bone.

In March a mail rider between Prairie Bluff and Old Washington Courthouse noticed him working on his fossils. He told Koch that he had heard of a 90-foot-long petrified shark at the courthouse, which people had tried to dig up, only to realize that the bones were too heavy to move. Apparently the mail rider had a fair amount of time on his hands, because when Koch showed interest he rode the 40 miles to Old Washington Courthouse to see if the bones were still there. Koch waited nervously for him to return. Three men and a woman from New York stopped to talk to him while the mail rider was gone, and they told him that they were trying to find the sea serpent's fossils as well. At the time, sea serpents were much on the public's mind, both in the United States and in Europe, with sailors claiming to have seen living monsters swimming alongside their ships. The possibility that their bones were lying in the wilds of Alabama was irresistible. Two days later the mail rider came back to Clarksville and told Koch that the fossil hadn't been moved.

Koch rode alone to Old Washington Courthouse, through forests wrecked by storms and valleys full of yellow fever. When he reached the little town, he found that the fossils the mail rider had described were not of a shark but still more vertebrae from the sea monster. Koch locked them in the abandoned jail. A white boy and a slave watching him wrestle with the bones told him about fossils still in the ground. They led him to a field by the Sintabogure River, where he saw what he had dreamed of: bones of the great serpent laid out in a huge half-circle.

For three months Koch excavated the Sintabogure fossils. Here around Old Washington Courthouse the bones were even more common than they were at Clarksville: people used them as garden gates, burned them for lime, set them in chimneys as cornerstones, and slept on them as pillows. Koch ham-

**People used the bones
as garden gates, burned
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mered away at his fossilized bones in the scorching sun, burning his skin on the iron tools, working alone after he fired a drunk assistant, fending off gawkers who accidentally broke the giant jaw. By the time he was through, he had filled five wagonloads with fossils, the biggest haul of whale bones the world had ever seen.

It's hard to judge whether Koch was aware that *Basilosaurus* was actually a whale. While traveling with *Missourium*, he passed through London just three years after Harlan's public turnaround. When he'd found a skull along the Sintabogure, he noted in his journal that it had teeth like a mammal's. If he did know that what he had was a whale, he certainly kept the truth to himself: by August the New York newspapers were filled with articles about the 114-foot-long sea serpent that was on display in the Apollo Saloon on Broadway, discovered by Dr. Albert Koch, as he now called himself. "The serpent of the Deucalion deluge, slain by Apollo Pythius, is beheld, with scarcely the aid of the dullest fancy," said the *New York Dissector*. The *New York Evangelist* was more reverent: "Who knows but he had seen the Ark? Who knows but Noah had seen him from the window? Who knows but he may have visited Ararat? Who knows how many dead and wicked giants of old he had swallowed and fed upon? Perhaps when we touch his ribs, we are touching the residuum of some of Cain's descendants that perished in the deluge."

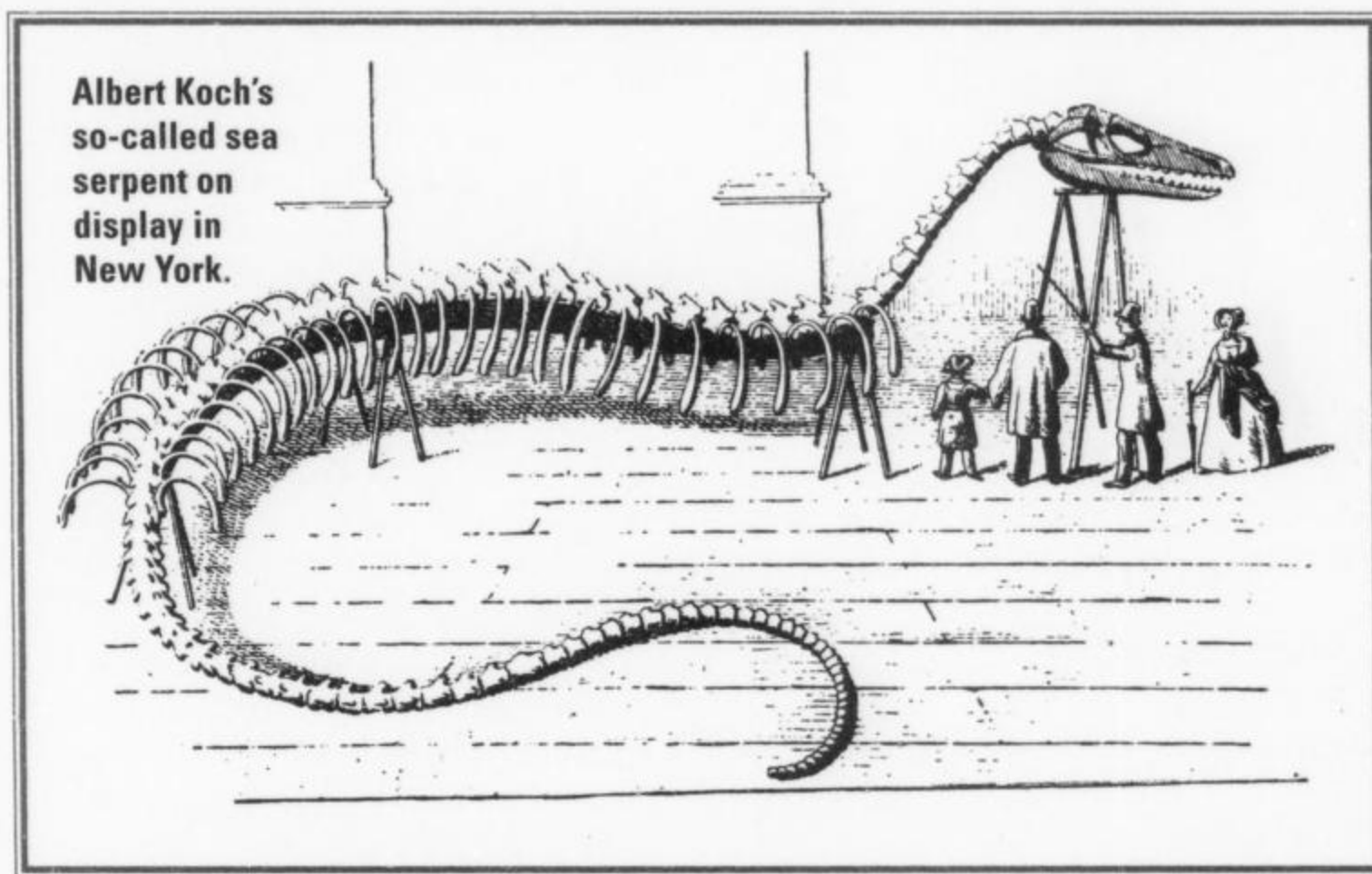
Scientists were not so kind. As with *Missourium*, they saw that the serpent's spine was not from a single creature but from five, all of whom were not sea serpents but extinct whales. Koch responded to American critics by fleeing once again with his bones. He displayed them in Leipzig, and King Frederick Wilhelm IV of Prussia was so impressed that he bought the fossils for his anatomy museum, giving Koch a stipend for life. Koch went back to Alabama in 1848 and found more bones, which he strung out as a 96-foot-long serpent and brought back to Europe.

Eventually Koch settled back down in St. Louis, calling himself a professor of philosophy. From time to time he would look in Tennessee for seams of iron or coal, but never for a fossil. In 1871 his collection of bones was destroyed in a Chicago fire, but Koch would not be remembered as an absolute hoaxer. While exhuming *Missourium*, he had discovered stone blades around the bones, and he suggested for the first time that Indians had lived alongside the mastodons. Much later he would be shown to have been right. He died after a few years of "lingering torpor of the liver," and later, when workmen disinterred his body for reasons unrecorded, they were shocked to find that it had petrified. The paleontologist had become his own fossil.

BEFORE DARWIN, TAXONOMISTS HAD A DIFFICULT time putting whales in their proper place. Aristotle set them off in a group of their own, as distinct as birds or insects, but by 1700 biologists had recognized that they were actually mammals. When Darwin wrote *On the Origin of Species*, the oldest fossils of whales were the likes of *Basilosaurus*, fully aquatic animals that shared so many of the strange features of living cetaceans that they couldn't show how they might have come from land. After Koch's discoveries, the nineteenth century saw the discovery of a few more ancient whales. *Basilosaurus*, it became clear, was only 50 feet long, while other species reached a more modest 15 feet. In general they were snakier than today's whales, with slender flippers, nostrils close to the ends of their snouts, and a mix of teeth in their mouths unlike the rows of pegs in living toothed whales. Like any whale today, they apparently lacked hind legs and could obviously have lived only in water. How they got there was anyone's guess.

In theory, at least, Darwin didn't think this mystery was uncrackable. "In North America," he wrote, "the black bear was seen by Hearne swimming for hours with widely open mouth, thus catching, like a whale, insects in the water. Even in so extreme a case as this, if the supply of insects were constant, and if better adapted competitors did not already exist in the country, I can see no difficulty in a race of bears being rendered, by natural selection, more and more aquatic in their structure and habits, with larger and larger mouths, till a creature was produced as monstrous as a whale." The suggestion did not go over well among a public trying to bend their minds around the idea

of natural selection. As one newspaper sniffed, "Mr. Darwin has, in his most recent and scientific book on the subject, adopted such nonsensical 'theories'—as that of a bear swimming about a certain time till it grew into a whale, or to that effect." Darwin chose not to fight this particular case of Lamarckian confusion: in later editions of



Species, he left out most of his speculations about whales.

It was up to the next generation of biologists to think seriously about the origin of whales, and none thought as much about it as the English zoologist William Flower. Flower was 28 when he read *On the Origin of Species*, and he was soon pulled into the bitter confrontations that followed its publication. But unlike other biologists in the great Darwinian debate, he didn't end up dripping with rancor: his biography reads from start to finish like a pleasant stroll. As a child he built himself little museums in cardboard boxes and then a cupboard, and by the time he had turned 21 he was a medical

student who had dissected exotic primates such as the galago. He served in the Crimean War, where half his regiment died during the bloody fall of Sevastopol and the Battle of Balaklava, but the horror threw no apparent shadow on his later life.

By the 1860s Flower had taken Richard Owen's old post at the Hunterian Museum, and like his predecessor he dissected his way through a menagerie of animals. He was the first scientist to see the inside of a panda. He examined manatees, chimps, Burmese elephants, pygmy rhinos, sloths, armadillos, howler monkeys, red wolves, and musk deer.

Flower had almost as many causes as animals under study—he protested the slaughter of ospreys to decorate hats with their plumes, he raged against the killing of bottle-nosed dolphins for oil to keep clocks running smoothly. He thought that people should stop the unhealthy practice of burying the dead in sealed coffins and cremate them instead. He weighed in against tobacco, corsets, foot-binding, high-heeled shoes, and that the post office charged more to send a heavy letter than a book. Natural selection frightened Owen with its bestiality, while for Darwin, who suffered a series of deaths in his family, God and nature became equally dark. Yet Flower folded evolution peacefully into his comfortable Victorian life.

Some of Flower's most important mammal work was with whales, and toward the close of his career, he gave their origins a lot of thought. Fossil whales like *Basilosaurus*—so aquatic already—offered him little help, but simply comparing living whales with other mammals might be enough, he thought, if done in the right way. "Scarcely anywhere in the animal kingdom do we see so many cases of the persistence of rudimentary and apparently useless organisms, those marvelous and suggestive phenomena which at one time seemed hopeless enigmas, causing despair to those who have tried to unravel their meaning, looked upon as mere will of the wisps, but now eagerly welcome as beacons of true light, casting illuminating beams upon the dark and impenetrable paths through which the organism has traveled on its way to reach the goal of its present existence."

The challenge as Flower saw it was to decide which way the paths went. Were whales the aquatic ancestors of all mammals—a notion of some early Lamarckians—or had their own ancestors lived on land as Darwin had suggested? Mammals as a rule are furry, but the sleek skin of whales is bare save for a few hairs around their blowholes or their chins. Although whales probably couldn't smell, the blowhole still connected to the main airway as did the nostrils of mammals on land. And while Flower assumed that whales must be deaf because the passageway was practically clotted shut—"like a hole made by the prick of a pin"—they still had the ear bones of a mammal. Their fins were actually fingered arms that had been sealed over, and deep inside the blubber at the back of the body were bits of bone and cartilage. In some species, two of these bones

fit together like a hip and femur. At the far end of the so-called femur was a capsule of fluid, a vestige of a vanished knee. Even the muscles around these abandoned bones permitted and restrained different movements in the same way that the muscles around a horse's hind legs do.

Flower concluded that some conventional land mammal, complete with four legs, placenta, hair, teeth, and a working nose, gave rise to whales. Ancient whales such as *Basilosaurus* were exactly what we would expect the early aquatic descen-

dants of these creatures to be: they had small skulls, with nostrils closer to the front of their noses. And early whales had a mix of molars and premolars and incisors much like the kinds found in the mouths of mammals on land.

Flower cast about for a genealogy leading into the sea. He doubted that seals could be the closest relatives of whales despite their being intermediate in their adaptation to water. Instead of raising and lowering a giant tail as whales do, seals kick their hind legs from side to side, with barely a tail between them. It seemed unlikely that a lineage of animals that had already committed to swimming this way would produce descendants that would shrink their feet back down in order to increase

their tails. Flower thought that a whale ancestor might look like one of the big-tailed, semiaquatic mammals like otters and beavers. In a few details in the liver and lungs, anatomists had already found similarities between whales and the hoofed mammals (known as ungulates), and so perhaps the names that people had given to whales—sea hogs, sea pigs, herring hogs, and the French *porcpoisson* (from which the word *porpoise* comes)—weren't so far off.

"We may conclude," Flower wrote, "by picturing to ourselves some primitive, generalized, marsh-haunting animals with scanty covering of hair like modern hippopotamuses, but with broad, swimming tails and short limbs, omnivorous in their mode of feeding, probably combining water plants with mussels, worms, and freshwater crustaceans, gradually becoming more and more adapted to fill the void place ready for them on the aquatic side of the borderland on which they dwelt, and so by degrees being modified into dolphinlike creatures, inhabiting lakes and rivers, and ultimately finding their way into the ocean. Favored by various conditions of temperature and climate, wealth of food supply, almost complete immunity from deadly enemies, and illimitable expanses in which to roam, they have undergone the various modifications to which the cetacean type has now arrived, and gradually attained that colossal magnitude which we have seen was not always an attribute of the animals of this group."

Flower ended with a warning. "Please recollect, however, that this is mere speculation, which may or may not be confirmed by subsequent paleontological discovery." The discovery would take over a century, but today paleontologists look back at Flower as almost clairvoyant. ▢

**Which way had the
evolutionary paths gone?
Were whales the aquatic
ancestors of all
mammals, or had their
ancestors lived on land?**